General Relationships Among Plants and Their Alkaloids

It is intriguing to botanists and chemists alike to seek interrelations between taxonomic units of plants and their chemical components. Many have indulged in this search, sometimes with useful results. Henry (1) reviews a number of instances where alkaloids were used to contribute to taxonomic problems, and Manske (2) considered them in relation to the whole phylogenetic scheme of the angiosperms. McNair (3) digressed from taxa and considered the size of alkaloids as it might be reflected in the habitat of the families containing them. For example, he deduced that the average molecular weight of alkaloids was greater in temperate than in tropical families; that the average number of nitrogen and carbons was the same in the two groups, but that the number of oxygens was greater in the temperate.

With the advent of a recent complete compilation of alkaloid-bearing plants and their contained alkaloids (7), some 3600 species of plants and 2000 alkaloids, we felt that here was an unusual opportunity to make a further study of the distribution of this group of components. The present paper deals with the size of alkaloids as reflected by habit, habitat, family, geographical location; their frequency of occurrence; their distribution. No attempt is made to interpret the findings.

Sample

A systematic sampling of the plants in the above-mentioned bulletin (7) was prepared by selecting every tenth species. The

name of each species was entered on a card, together with the family, the number of carbon atoms in each of its contained alkaloids, whether it was woody or herbaceous in habit and whether it was temperate or tropical in habitat. Those intermediate in character (sub-woody, warm-temperate, sub-tropical) were discarded, leaving 244 species with 648 alkaloids for analysis. Table 1 gives the groupings made for comparisons.

Conventions and Calculations

In characterizing the nature of the alkaloids in the various groups under comparison, their chemical structure would be the most desirble item to use. Because of the great diversity of this character, however, it did not seem to be feasible. Therefore, the size of the molecule, or actually the number of carbon atoms, was chosen. Since the great majority of the alkaloids, irrespective of molecular weight, contain from 65 to 75% carbon, we felt that the use of the number of carbon atoms instead of molecular weight would be simpler and sufficiently precise for our purposes; and we use the terms "size of the alkaloid" for brevity.

TABLE 1
DISTRIBUTION AS TO HABIT AND HABITAT OF THE 10% SAMPLE OF SPECIES

	Number of Species	Alkaloids
Temperate	109	285
Herbaceous	88	220
Woody	21	65
Tropical	135	362
Herbaceous	20	45
Woody	115	317
Herbaceous	108	265
Temperate	88	220
Tropical	20	45
Woody	136	382
Temperate	21	65
Tropical	115	317

TABLE 2
COMPARISONS OF ALKALOID SIZE IN THE FOUR
GROUPS OF SPECIES

| | Number of | | Ave. no. | |
	Species	Alkaloids	of C's	"t" value
1. Tropical-herbaceous	20	45	19.15)	
2. Tropical-woody	115	317	20.01)	0.5752
3. Temperate herbaceous	88	220	18.59)	
4. Temperate-woody	21	65	20.94)	2.1461*
All tropical (1+2)		362	19.91)	1.060
All temperate (3+4)		285	19.26)	
All herbaceous (1+3)		265	18.68)	
All woody (2+4)		382	20.17)	2.395*
2. Woody-tropical		317	20.01)	
4. Woody-temperate		65	20.94)	----------
1. Herbaceous-tropical		45	19.15)	----------
3. Herbaceous-temperate		220	18.59)	0.456

* Significant at 5%.

The differences between groups were evaluated by analysis of variance or by the "t" test or by both.

Habit and Habitat

When all cards were separated into temperate and tropical, irrespective of habit, no difference in size of alkaloids was found. When all cards were separated into herbaceous and woody, irrespective of habitat, the woody showed greater size of alkaloids.

Then all cards were separated into four groups—tropical-woody, tropical herbaceous, temperate-woody, temperate-herbaceous. The data are given in Table 2. Again, the woody species show larger alkaloids, especially in the temperate group. The habitat zones show no difference.

When the habitat intermediates—sub-tropical and warm-temperate—were included in the comparisons, the data in Table 3 were

obtained. With both woody and herbaceous species, plants grown in the temperate and tropical zones contain alkaloids with the same number of C atoms. The alkaloids found in plants of the sub-tropical and warm-temperate zones, while differing almost significantly from each other, contain significantly fewer C atoms than do the alkaloids found in plants of the tropical and temperate zones. In other words, so far as influence of plant habitat on size of alkaloids is concerned, the tropical and temperate zones have more in common with each other than either has with the intermediate zones.

A few families contained sufficient alkaloid species to allow, in part, an analysis of habit and habitat within the family. In the Leguminosae, alkaloids in the temperate-woody and -herbaceous had the same size, but the tropical-woody were greater than temperate woody. In the Rutaceae, the tem-

TABLE 3
HABITAT COMPARISONS WITH INTERMEDIATE ZONES INCLUDED.
FIGURES ARE AVERAGE NUMBER OF CARBON ATOMS.

	Tropical	Temperate	Warm-Temperate	Sub-Tropical	Difference*
Herbaceous	19.1	18.6	15.6	14.5	2.5
Woody	20.0	20.6	13.9	16.3	2.6

*Difference required for siginificance (p = 0.05) by Duncan's multiple range test.

perate-woody was greater than the tropical. In the Solanaceae, tropical-herbaceous were somewhat larger than temperate-herbaceous. In the Liliaceae and Amaryllidaceae, tropical and temperate were equal, all being herbaceous.

Monocots and Dicots

All cards of the 10% sample, irrespective of habit and habitat, were collected in these two groups, giving 48 alkaloids in the monocots and 600 in the dicots. Analysis of variance showed no difference in number of carbons between the two groups.

Since, however, this gross comparison could well be clouded by the effects of habitat and habit given above, it seemed desirable to make comparisons within the subgroups. Since the number of alkaloids in the 10% sample of monocots was too small for this division, all monocot species in the bulletin were collected. And since the only "woody" monocots were the Palmae, with 6 alkaloids, these were excluded. The herbaceous monocots were then compared with the herbaceous dicots, with the results given in Table 4.

Conclusions from the table are: In the temperate zone, the alkaloids of the monocots are larger than those of the dicots; in the tropic, the reverse holds; within the monocots, those in the temperate zone are larger; within the dicots, the tropical tend to be larger.

Another selection of cards concerned the dicots of the temperate zone. Again the woody showed larger alkaloids than the herbaceous.

Australian Plants

We were curious to know whether plants indigenous to geographically isolated Australia would differ as to the size of their alkaloids from comparable plants from the rest of the world.

By comparing the bulletin with three Australian surveys of alkaloid plants (4, 5, 6), 51 species were found which were native to Australia, which contained known alkaloids, and which could be assigned to the four habit and habitat groups. Only one pair, tropical-woody, with 35 species and 124 alkaloids, was large enough for statistical comparison. These were compared with the tropical-woody from the rest of the world (106 species, 277 alkaloids). The Australian had an average of 20.29 C's and the other group 16.99. This was significant at 0.5% level. This difference was in spite of the presence in the Australian sample of 7 species of Acacia with an average of only 9 C's, whereas the non-Australian legumes had an average of about 16. The Australian Rutaceae averaged 16.4 C's, the non-Australian 15.4.

Family Characteristics

Eighteen families were selected, varying in number of alkaloids from 11 to 190 and in number of alkaloid-bearing species from 20 to 525. The number of C's was plotted against the number of alkaloids having each number of C's. The bar graph of Figure 1 gives the results. Items of note:

TABLE 4
COMPARISON OF HERBACEOUS MONOCOTS WITH HERBACEOUS DICOTS.

| | Number of | | Ave. no. | "t" value |
	Species	Alkaloids	of C's	
Monocot-Temperate	97	287	23.72)	
Dicot-Temperate	74	190	18.16)	10.28 a
Monocot-Tropical	42	101	16.51)	
Dicot-Tropical	14	33	19.73)	3.35 a
Monocot-Temperate	97	287	23.72)	
Monocot-Tropical	42	101	16.51)	12.77 a
Dicot-Temperate	74	190	18.16)	
Dicot-Tropical	14	33	19.73)	1.65 b

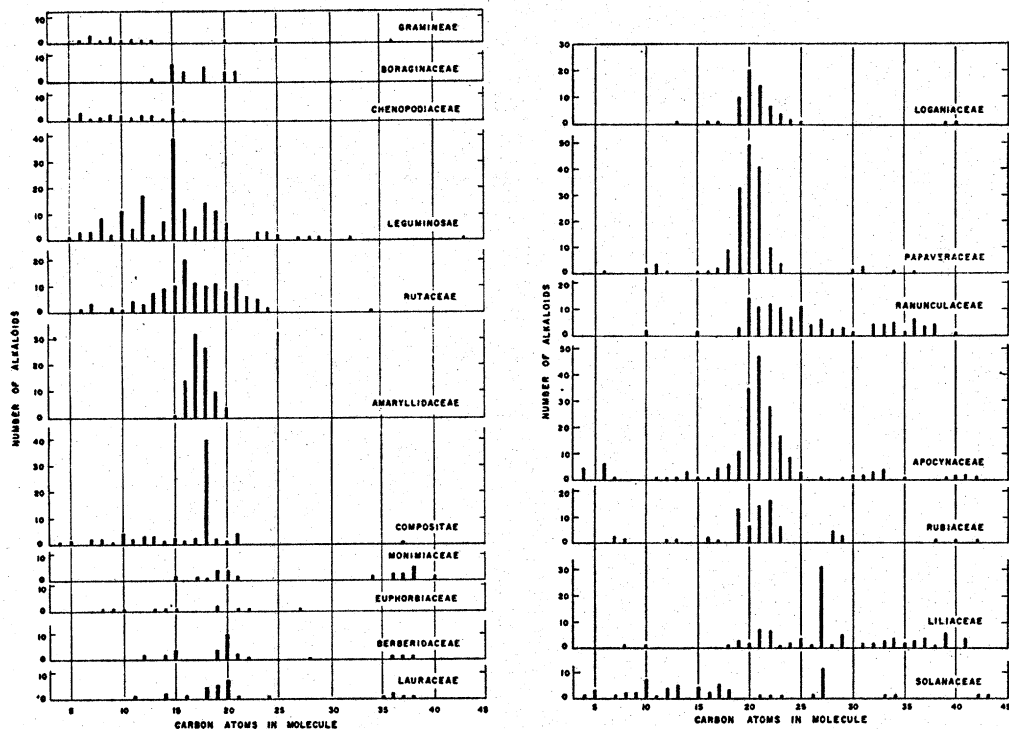a Significant at 0.1%.
b Significant at 10%.

Fig. 1. Distribution of alkaloid sizes in families.

1. There is a tendency in many families for the alkaloid size to follow a normal distribution curve, or, so to speak, for the family to "specialize" in alkaloids of a certain size. Examples: Apocynaceae, Amaryllidaceae.

2. Other families show no such tendency. Examples: Solanaceae, Chenopodiaceae.

3. In general, the families with the largest number of alkaloids have the highest degree of specialization in size of alkaloid. If the number of alkaloids is less than about 60, no specialization has developed.

4. The peak of alkaloid size is characteristic of the family, and in those of well marked peaks it varies from 15 C's to 27.

5. Liliaceae are unique in having 31 alkaloids of 27 carbons and not more than 7 alkaloids with any other number of carbons. Similarly, the Compositae have 36 alkaloids with 18 carbons, and not more than 4 with any other number of carbons. The Amaryllidaceae are unique in having 88 alkaloids of only 6 sizes, with a highly symmetrical distribution curve.

6. There is no distinction in the above matters between monocots and dicots.

7. In general, the larger the number of alkaloids in a family the greater the number of different sizes, but marked exceptions to this are the Amaryllidaceae, Papaveraceae and Solanaceae.

Of the families with 60 or more alkaloids, Solanaceae have the greatest spread with the least tendency to specialize in one size of alkaloid. In fact, there is some tendency for the distribution chart to be bi-modal. When the 10% sample was separated into tropical and temperate (all herbaceous), there was evidence that the tropical is larger than the temperate. The number of alkaloids is small, however (7 for tropical, 12 for temperate, as against about 60 for the whole family).

Distribution of Individual Alkaloids

A list was compiled of 52 alkaloids which occur in 17 or more species, with the number of families, genera and species in which each occurs and the empirical formula (see Table 5).

TABLE 5
DISTRIBUTION OF THE 52 MOST PREVALENT ALKALOIDS

		Occurrence in Families	No. of Genera	Species
Aconitine	$C_{34}H_{47}NO_{11}$	1	1	32
Ajmaline	$C_{20}H_{26}N_2O_2$	1	2	17
α-allocryptopine	$C_{21}H_{23}NO_5$	2	17	33
Anabasine	$C_{10}H_{14}N_2$	3	4	23
Anagyrine	$C_{15}H_{20}N_2O$	1	9	25
Atropine	$C_{17}H_{23}NO_3$	1	7	17
Berbamine	$C_{37}H_{40}N_2O_6$	3	4	17
Berberine	$C_{20}H_{19}NO_5$	7	26	89
Caffeine	$C_8H_{10}N_4O_2$	14	28	66
Chelerythrine	$C_{21}H_{17}NO_4$	2	13	19
Cinchonidine	$C_{19}H_{22}N_2O$	2	3	20
Cinchonine	$C_{19}H_{22}N_2O$	1	2	26
Colchicine	$C_{22}H_{25}NO_6$	2	16	49
Cytisine	$C_{11}H_{14}N_2O$	2	18	67
Emetine	$C_{29}H_{40}N_2O_4$	2	13	17
Ephedrine	$C_{10}H_{15}NO$	6	6	25
ψ-ephedrine	$C_{10}H_{15}NO$	5	5	21
Erysodine	$C_{18}H_{21}NO_3$	1	1	22
Erysopine	$C_{17}H_{19}NO_3$	1	1	21
Erysovine	$C_{18}H_{21}NO_3$	1	1	23
Galanthamine	$C_{17}H_{25}NO_3$	1	14	29
Haemanthamine	$C_{17}H_{19}NO_4$	1	14	29
Hyoscine	$C_{17}H_{21}NO_4$	2	8	32
Hyoscyamine	$C_{17}H_{23}NO_3$	3	8	35
Hypaconitine	$C_{33}H_{45}NO_{10}$	1	1	17
Hypaphorine	$C_{14}H_{18}N_2O_2$	1	1	26
Isocorydine	$C_{20}H_{23}NO_4$	5	11	17
Jatrorrhizine	$C_{20}H_{21}NO_5$	3	10	30
Lupanine	$C_{15}H_{24}N_2O_2$	3	9	32
Lycorine	$C_{16}H_{17}NO_4$	1	30	85
Magnoflorine	$C_{20}H_{24}NO_4$	6	15	23
Mesaconitine	$C_{33}H_{45}NO_{11}$	1	1	23
N-methyl-cytisine	$C_{12}H_{16}N_2O$	3	12	25
Nicotine	$C_{10}H_{14}N_2$	9	12	69
Nornicotine	$C_9H_{12}N_2$	2	4	48
Palmatine	$C_{21}H_{23}NO_5$	7	15	45
Phenethylamine	$C_8H_{11}N$	3	4	35
Protopine	$C_{20}H_{19}NO_5$	3	25	79
Quinidine	$C_{20}H_{24}N_2O_2$	2	4	19
Quinine	$C_{20}H_{24}N_2O_2$	3	6	32
Rescinnamine	$C_{35}H_{42}N_2O_9$	1	2	18
Reserpine	$C_{33}H_{40}N_2O_9$	1	5	46
Sanguinarine	$C_{20}H_{13}NO_4$	3	13	18
Senecionine	$C_{18}H_{25}NO_5$	2	4	25
Skimmianine	$C_{14}H_{13}NO_4$	1	16	28
Solanidine	$C_{27}H_{43}NO$	1	4	58
Sparteine	$C_{15}H_{26}N_2$	4	18	67
Stachydrine	$C_7H_{13}NO_2$	7	10	25
Tazettine	$C_{18}H_{21}NO_5$	1	14	30
Theobromine	$C_7H_8N_4O_2$	5	6	19
Trigonelline	$C_7H_7NO_2$	12	23	32
Yohimbine	$C_{21}H_{26}N_2O_3$	4	8	20

Distribution in Families: caffeine 14; trigonelline 12; nicotine 9; palmatine and stachydrine 7; ephedrine and magnoflorine 6; ψ-ephedrine, isocorydine and theobromine 5; sparteine and yohimbine 4. Ten occur in 3 families, 10 in 2, and 19 in 1.

Distribution in Genera: lycorine 30; caffeine 28; berberine 26; protopine 25; trigonelline 23. Seven occur in but 1 genus.

Distribution in Species: berberine 89; lycorine 85; protopine 79; nicotine 69; sparteine and cytisine 67; caffeine 66; solanidine 58; colchicine 49; nornicotine 48. It is noteworthy that 1443 occur in but one species.

An index of diversity of distribution is the ration of occurrence in species to that in families, a high ratio indicating specialization of this alkaloid in 1 or a few families, a low ratio meaning meager specialization. Some of the highest and lowest: lycorine 85; solanidine 58; reserpine 46; nicotine 8; caffeine ; magnoflorine, theobromine, ψ-ephedrine, 4; isocorydine 3.

When the occurrences in number of families was plotted against the size of the alkaloid (number of C's), there was some tendency for the largest alkaloids to have the lowest family distribution, and the reverse. Thus of 6 alkaloids of 33 or more C's, 5 occurred in only one family and 1 in 3 families; and the 5 alkaloids with 7 and 8 C's occurred in 3, 5, 7, 12 and 14 families.

Summary

A statistical analysis was made of the 3600 species of plants known to contain alkaloids and their 2000 alkaloids to determine distribution by families, diversity of occurrence of individual alkaloids, how the size of the alkaloids (number of carbons) in species may be correlated with habit, habitat, family and geographic location. The categories used for comparison were woody, herbaceous, temperate, tropical, monocot, dicot and native to Australia.

Woody-temperate species have larger alkaloids than herbaceous-temperate. All woody, including both temperate and tropical, have larger alkaloids than all herbaceous.

In both herbaceous and woody, the strictly tropical and temperate species have larger alkaloids than the sub-tropical and the warm-temperate.

Within the herbaceous species, monocot-

temperate have much larger alkaloids than dicot-temperate, but those of the dicot-tropical are larger than the monocot-tropical.

In families containing 60 or more kinds of alkaloids, there is a tendency for the number of alkaloids having the same number of carbons to follow a normal distribution curve, or, so to speak, for the family to specialize in aklaloids of a given size. The peak, or the size representing the greatest number of alkaloids, is characteristic of the family and varies from 15 to 27 carbons.

Caffeine occurs in the largest number of families (14), lycorine in the largest number of genera (30) and berberine in the largest number of species (89).

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